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Background Levels of Contaminants in Soils in Scotland

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Prompted by growing concerns about man's impact on the environment and environmental impacts on man, many national governments and international agencies are developing policies to protect land and water quality. In the UK, some of the main legislative drives are the Government targets for sustainable development, which focus on the re-use of Brownfield sites for 60% of new residential homes. Whilst this policy protects green belts around urban environments, Brownfield sites include land that may or may not be contaminated with chemical substances that are potentially harmful to life. Although links between long term human health effects and potentially harmful substances (PHSs) are often difficult to prove, the majority of regulatory authorities adopt a precautionary principal approach to legislate against high environmental concentrations of PHSs.

In the UK, the Environmental Protection Act, Part IIa (1990) was implemented on 1st April 2000 in England, 14th July 2000 in Scotland and 1st July 2001 in Wales. The Act places the responsibility for the identification, assessment, remediation and monitoring of contaminated land with Local Authorities (LAs) as follows:

Environmental Protection Act, Part IIa (1990)
Definitions:
<i>Contaminated land is defined as:</i> "any land which appears to the local authority in whose area it is situated to be in such a condition by reason of substances in, on or under the land that: Significant harm is being caused or there is a significant possibility of such harm being caused or Pollution of controlled water is being or likely to be caused"
<i>Harm is defined as:</i> "harm to the health of living organisms, or other interference with the ecological systems of which they form a part, and in the case of man, harm to his property"

The Act addresses the pollution of waters and threats to ecosystems and buildings in addition to human health risks and operates a 'polluter pays' principle in terms of remediation. However, it is important to point out that Part IIa only applies to a subset of land that is chemically contaminated. The identification of contaminated land relies on the concept of risk assessment, based on a pollutant linkage whereby the presence or source of contamination has the potential to impact on a receptor by

means of a pathway (Figure 1). If the linkage does not exist then, in terms of the Act, the land is not contaminated. Thus, for example, an area of ground could contain high concentrations of a PHS but if this is not affecting water resources, property, living organisms or ecosystems then it will not be classified as contaminated.

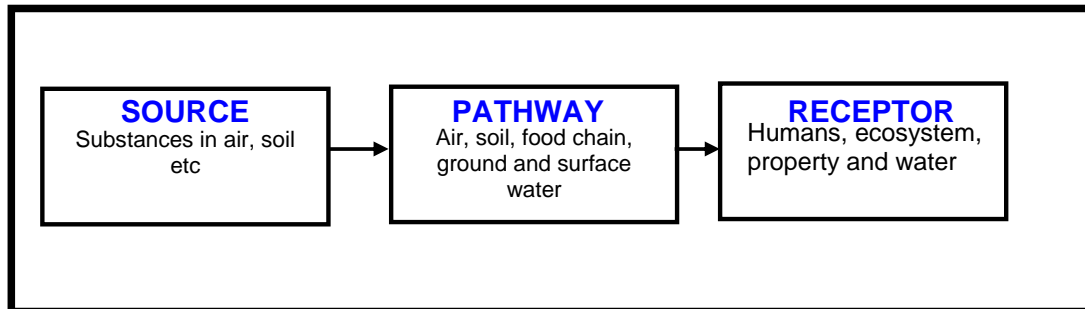


Figure 1. Concept of source, pathway and receptor in the assessment of contaminated land (From Fordyce and Ander, 2003)

The statutory duties of the LAs under Part IIa include:

- Inspection of LA area to identify potential contaminated land
- Determine contaminated land
- Establish whether sites should be designated as ‘special sites’ and thus become the responsibility of the Environment Agency (EA) or Scottish Environmental Protection Agency (SEPA)
- Serve remediation notices where necessary
- Undertake assessment of the best practical remediation option -and tests for reasonableness
- Consult other parties including the EA/SEPA
- Compile and maintain contaminated land registers
- Consult the EA/SEPA on pollution of controlled waters

As a first stage, the Act required LAs to adopt and implement a strategy for identifying and prioritising contaminated land, involving the collation of current and historical information on the distribution of potential receptors, the movement of contaminants in the environment and on contaminant sources.

Several guidelines exist to aid the identification, assessment and management of contaminated land. In terms of water quality, the World Health Organisation (WHO) defines maximum admissible concentrations (MACs) of PHSs in drinking water (WHO, 1996). The European Union Water Quality Framework Directive (CEC, 1998) incorporates many of the WHO values and is the legislative basis for water suppliers and regulatory authorities in the UK. Similarly, many governments devise standards for soil quality.

Included in these types of regulations are the man-made organic compounds many of which are detrimental to health such as the polynuclear aromatic hydrocarbons (PAHs), which have been linked to cancer, the polychlorinated biphenols (PCBs), and the endocrine system disrupting chemicals that affect metabolic activity control. However, the guidelines also deal with several natural substances such as the metal elements arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb) and mercury (Hg).

In fact there are 92 naturally occurring chemical elements on the Earth, which form the building blocks of the planet and rocks, soils, waters, gases and all living things are made from them. Hence chemicals are around us and in us all the time. Approximately 26 of these chemical elements, including Ca, Mg, Fe, Co, Cu, Zn, P, N, S, Se, I and Mo, are fundamental for life or essential to health in trace amounts. On the other hand, an over-abundance of these elements can cause toxicity problems. Some elements such as As, Cd, Pb, Hg and Al have no/limited biological function and are generally toxic to humans. Hence the distribution of these potentially harmful elements (PHEs) in the environment is of concern.

In the UK, the major pathways via which these PHEs can enter the human body are through inhalation of dusts and gases and contact with soil in gardens, play areas and allotments etc. Soil ingestion can be inadvertent for example on homegrown vegetables or from hand to mouth contact, especially in children. Deliberate eating of soils is also common among children. Water is unlikely to pose a risk to human health due to the high standard of public water quality in the UK and the minimal use of private wells in most built-up areas; however, the protection of water resources is a major issue under the current legislation.

In order to assess these substances in terms of soil exposure, the UK Government Interdepartmental Committee for the Redevelopment of Contaminated Land (ICRCL, 1987) guidelines provided maximum recommended thresholds or trigger values for contaminants in soil depending on the land use (Table 1).

Table 1. Examples of the ICRCL (1987) trigger values for PHSs in soils

Substance	ICRCL Trigger Value mg/kg (ppm)		
	Domestic Gardens and Allotments	Parks, Playing-fields and Open Spaces	Anywhere Plants are to be Grown
Arsenic	10	40	
Cadmium	3	15	
Chromium	600	1000	
Chromium ⁶⁺	25		
Lead	500	2000	
Mercury	1	20	
Selenium	3	6	
Boron*			3
Copper*			130
Nickel*			70
Zinc*			300
Polycyclic Aromatic Hydrocarbons	50		
Phenols	5		
Free cyanides	25		
Sulphide	250		

Guidelines are based on total element concentrations in < 2-mm soils

* Elements that are rarely hazardous to human health but are phytotoxic (injurious to plants)

The Government has now withdrawn the ICRCCL (1987) Guidelines in favour of the new risk assessment tool for human exposure known as the Contaminated Land Exposure Assessment (CLEA) model. Initially devised by Nottingham University, the model was further developed by the EA and to date includes risk assessment information for As, Cd, Cr, cyanide, Pb, Hg, Ni, phenols, PAHs and Se. In due course, the Government aims to provide information for approximately 50 PHSs.

The Government does not prescribe any particular risk assessment model for contaminated land investigations and other software packages are currently available. In terms of human health risk, these packages are based on ecotoxicological information whereby physiological responses to doses of chemicals are established, often using animal experiments. An uncertainty factor is then applied to determine an index dose value for humans. The CLEA guidelines focus on the likely exposure to this dose from soil and use this information to derive soil guideline values (SGV). On this basis 'typical' SGVs for As, Cd, Cr, Pb, Hg, Ni and Se have been defined (Table 2).

Table 2. 'Typical' soil guideline values (SGVs) derived from the CLEA risk assessment model (EA, 2004).

All values in mg/kg dry weight soil				
Pollutant	Residential with plant uptake ^[A]	Residential without plant uptake ^[B]	Allotments ^[C]	Commercial/ industrial ^[D]
Arsenic (As)	20	20	20	500
Cadmium (Cd)	1 (pH 6) 2 (pH 7) 8 (pH 8)	30	1 (pH 6) 2 (pH 7) 8 (pH 8)	1400
Chromium (Cr)	130	200	130	5000
Mercury (inorganic Hg)	8	15	8	480
Nickel (Ni)	50	75	50	5000
Lead (Pb)	450	450	450	750
Selenium (Se)	35	260	35	8000

[A] House with a garden and therefore the possibility of ingestion of homegrown vegetables

[B] House or apartment with no private garden area

[C] Open space, often made available by the local authority, for people to grow fruit and vegetables for their own consumption

[D] Assumes that work takes place in a single-storey building, factory or warehouse where employees spend most time indoors involved in office-based or light physical work. Does not apply to sites with 100% hard cover, such as car parks

It is certainly the case that the UK has a long history of urbanization and industrialisation resulting in elevated concentrations of these PHEs derived from industrial and mineral processing and the atmospheric deposition of Pb and other toxins from traffic fumes. However, as well as anthropogenic inputs, PHE concentrations at any location are often controlled by factors such as geology, vegetation, soil forming processes and climate.

Geochemists and soil scientists have known the close association between the chemistry of rock parent materials and the soils developed over them since the 19th Century. Indeed the links are so profound that geochemists use element concentrations in soils to assist in mapping the underlying geology. Certain rock types such as coals, mudstones, shales and ironstones contain more As, Cd, Se, Pb, Hg than other rocks and As and Cd are also found in phosphatic deposits. Cr and Ni are associated with certain types of igneous and volcanic rocks but their concentrations in limestones and quartz-rich sandstones are generally low. All these elements can occur in very high concentrations in mineralised areas. Hence PHEs in rocks and the soils derived from them are not evenly distributed in the environment but by studying their spatial variability, geochemists and soil scientists are able to map their geochemical baseline signatures. This understanding of the 'natural' variability of these substances can allow local contaminated land assessments to be placed in the context of their surroundings and aid the identification of possible contaminant sources.

The word 'natural' is used with some reservation because man has interacted and altered the environment in Britain for thousands of years and it is probably true to say that there are precious few if any truly pristine areas left in this country. For example, even in the remote moorland areas of the Scottish Highlands, the land is burned and managed for grouse rearing and soils have been subject to atmospheric contaminants, particularly before implementation of the Clean Air Act in the 1960s. None-the-less, geochemical baselines can indicate near-natural or rural background concentrations of the PHEs over the various rock types present in an area.

There are five main sources of geochemical baseline information in the UK and their applicability to background concentrations of PHEs in Scotland is discussed below:

1. The Wolfson Geochemical Datasets of England and Wales and Northern Ireland

The Department of Environmental Science and Technology, Royal School of Mines, Imperial College, London, <http://www.ic.ac.uk>, hold the Wolfson geochemical datasets for England and Wales and Northern Ireland, which were collected as part of a pioneering geochemical survey carried out during the 1960s. These data are based on the analysis of stream sediment samples, which can be used as a proxy for soils in the surface environment. Total element concentrations were determined in the < 200- μ m fraction of stream sediments, collected at a sample density of 1 per 2.5 km². The data are published in the form of geochemical atlases, which show some PHE concentrations (including As, Cd, Cr, Ni and Pb) across England and Wales (Webb, 1978) and Northern Ireland (Webb, 1973). Whilst these data provide a useful overview of element concentrations in the environment, particularly in areas that have not yet been covered by more details surveys (see below), it should be noted that they were not produced to today's standards. For example, the samples were collected from the intersections of streams with roads therefore may be influenced by traffic pollution and not representative of background values. These data sets are not considered further here.

2. The Soil Database of Northern Ireland

The Agriculture and Environmental Science Division (AESD) of the Department of Agriculture and Rural Development (DARD), Belfast, Northern Ireland, <http://www.dardni.gov.uk/index.htm>, hold the soil database for Northern Ireland. As part of the database, pseudo-total (aqua-regia extraction) element concentrations in the < 2 mm fraction of top soils are available based on 7 000 agricultural soil samples collected at a density of 1 per 1 km² across the lowland areas of the province. These data have been published as a geochemical atlas, which shows some PHE distributions (Cd, Cr, Ni and Pb) in agricultural soils (Jordan et al, 2000). These data are interesting in that they provide an overview of average rural element concentrations in an environment, which in many respects is similar to Scotland against which contaminated sites can be assessed. However, it should be noted that because an aqua regia digest was used on the samples, the element values quoted might be lower than true total concentrations.

3. The National Soil Inventory of England and Wales

The National Soil Research Institute (NSRI), Cranfield University, Silsoe, Bedfordshire, <http://www.silsoe.cranfield.ac.uk/nsri/>, hold the National Soil Inventory for England and Wales. As part of the inventory, pseudo-total (aqua-regia extraction) element concentrations in the < 2 mm fraction of top soils are available based on 5692 rural samples collected at a density of 1 per 5 km² across England and Wales. These data have been published as a geochemical atlas, which shows some PHE concentrations (Cd, Cr, Ni and Pb) across England and Wales (McGrath and Loveland, 1992). In more recent years the NSRI have analysed a sub-set of the samples for As, Se and Hg content but these data have not yet been published. These data are useful in that they provide a national overview of average rural element concentrations in England and Wales against which contaminated sites can be assessed (Table 3). However, as with the Northern Ireland data, it should be noted that because an aqua regia digest was used on the samples, the element values quoted may be lower than true total concentrations.

Table 3. Summary of PHE concentrations in soils quoted in the Soil Geochemical Atlas of England and Wales (McGrath and Loveland, 1992).

	Cd mg/kg	Cr mg/kg	Ni mg/kg	Pb mg/kg
Minimum	<0.2	0.2	0.8	3
Maximum	40.9	838.0	440.0	16338
Mean	0.8	41.2	24.5	74

4. The National Soil Inventory of Scotland

The Macaulay Land Use Institute (MLURI), Craigiebuckler, Aberdeen, <http://www.mluri.sari.ac.uk/> hold the National Soil Inventory for Scotland. As part of the inventory, pseudo-total (aqua-regia extraction) element concentrations in the < 2 mm fraction of top soils are available based on approximate 1000 rural samples

collected at a density of 1 per 10 km² across Scotland. Data are available for Cd, Cr, Ni and Pb but have not yet been published in atlas format. These data are interesting in that they provide a national overview of average rural element concentrations in Scotland against which contaminated sites can be assessed (Table 4). However, as with the data for England and Wales, it should be noted that because an aqua regia digest was used on the samples, the element values quoted may be lower than true total concentrations.

Table 4. Summary of PHE concentrations in soils quoted from the National Soil Inventory for Scotland (SEPA, 2001).

	Cd mg/kg	Cr mg/kg	Ni mg/kg	Pb mg/kg
Minimum	0.02	2.3	0.4	3.9
Maximum	0.97	215.8	233	238.8
Mean	0.16	44.7	20.5	31.8

No analysis of As, Hg, or Se was carried out and whilst the data may provide some information on general trends across different types of geology and soil type, at only 1 sample per 10 km² the application to establishing local baselines may be limited.

The MLURI also carried out a survey of PAH, PCB, Cd, Cu, Ni, Pb and Zn concentrations at 30 locations on 4 Scottish Soil Transects focussing on upland organic soils. Samples were collected and analysed in 1990 and the results reported (<http://www.mluri.sari.ac.uk/tipss/scotst1.htm>). The same sites were revisited in 1999 to assess changes through time but the results have not yet been published. These data give a very general indication of the variability in PHS concentrations across Scotland but detailed information about each site would be required to ascertain the component of natural versus man-made influence on the distributions of these substances.

5. The Geochemical Baseline Survey of the Environment (G-BASE)

The British Geological Survey, Edinburgh and Keyworth, Nottingham www.bgs.ac.uk/gbase, is responsible for carrying out the strategic national geochemical survey of Great Britain (GB), the Geochemical Baseline Survey of the Environment (G-BASE). The mapping programme is based primarily on the collection of fine fraction (< 150 µm) rural stream sediments from first and second order streams at a sampling density of 1 per 1.5 km², which are analysed for a range of total element concentrations including As, Cd, Cr, Cu, Ni, Pb, Se, V, Sn, U and Zn by X-ray Diffraction Fluorescence Spectrometry (XRF). This survey started in the north of Scotland and has been working its way south down the country. Only in more recent years has soil sampling been incorporated into the programme, hence soil data are available from Mid England southwards. Soil sampling is based on the < 2 mm fraction of top (0.15 m) deeper (0.45 m) soils collected at a density of 1 per 2 km² in rural areas. The availability of data is outlined in Figure 1. The spatially registered chemical results are available digitally under licence from the BGS and are reported as a series of regional geochemical atlases (BGS, 1978 – 2000).

Although there is a lack of soil data for Scotland, a complete high-density stream sediment dataset does exist, which can be used as a proxy for soils. The variability of PHEs in the Scottish environment will be presented in relation to the controls on their distribution in the environment. For example, the geochemical map for Cu shows natural variability related to geology and mineralisation and man-made contamination on the fringes of the urban environments.

In addition to the stream sediment information for Scotland, soil samples collected in England over the same rock types as present in Scotland can be used to give an indication of background concentrations of PHEs. For example, soil data are available for the Humber Trent region of England. Part of this area is underlain by Coal Measure rock types similar to the Central Valley of Scotland therefore can be used as an indicator of background levels (Table 5).

Table 5. Median concentrations of PHEs in G-BASE rural soil samples collected over the Coal Measures in the Humber Trent region of England

	As mg/kg	Cd mg/kg	Cr mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Se mg/kg
Median	15	2.0	77	0.15	25	104	0.5

Traditionally the G-BASE programme avoided urban areas as the aim was to establish the rural geochemical baseline. However, in response to concerns about PHEs in the urban environment and the new statutory requirements on LAs, the mapping of urban centres commenced in 1992 and to date, 21 cities have been sampled. Urban surveying is based upon the collection of surface (0.15 m) and deeper (0.45 m) soil samples at a sampling density of 4 per km² and is designed to give a citywide overview of the geochemical signature. As part of this programme, approximately 1300 urban and 250 peri-urban soil samples were collected across the Glasgow conurbation during 2000 and 2001. These data will be reported and available under licence from the BGS by March/April 2004 and will be the first detailed systematic soil dataset for Scotland.

In assessing contaminated land, the emphasis is often very much on substances or chemicals that man has added to the environment and there may be a perception that these substances would not exist or would only be present in low quantities were it not for the influence of man. In fact natural concentrations of these PHEs can exceed the typical guideline values and levels in anthropogenically influenced environments.

Because the SGVs are worked back from ecotoxicological studies, they do not take account of the natural distribution of elements in the environment. For example, the typical SGV for As of 20 mg/kg is actually very low compared to the natural concentration range of the element in the environment. Hence situations arise whereby remediation may be recommended to levels below that present in the natural environment.

For example, BGS is doing work on behalf of Councils in Lincolnshire and Northamptonshire where As is a constituent of the Northampton ironstones and large

tracts of these counties exceed the 20 mg/kg SGV. The As is entirely natural and has been there for millions of years and questions arise as to whether tonnes of natural soil have to be remediated or removed to meet the SGV. Furthermore whether this As really poses a threat to health.

In order to assess these risks, BGS has developed tests to investigate how much As is taken up by humans through direct ingestion of soils or from soil attached to vegetables grown in gardens and allotments etc. These are the physiologically based extraction tests (PBET), which mimic conditions in the stomach and give an indication of bioaccessibility. For example the results show that although the total concentration of As in soils in the Northampton area is about 30 mg/kg, of this only around 6 mg/kg is bioaccessible. Such investigations can greatly reduce the number of sites considered to be of concern. The EA have commissioned a report on the PBET method, which will form another approach for the assessment of contaminated land, however, the selection of which assessment method to use still rests with the LAs.

In addition to information on the geochemical distributions of PHEs there are several techniques available to distinguish natural from anthropogenic sources. These include the chemical form of the element. For example in the case of Cr, most natural Cr is present in the Cr^{3+} form, whereas most man-made Cr is in the form of Cr^{6+} . In the case of Pb, isotopes of the element can be used to distinguish between local mineral sources and Pb derived from petrol as most Pb in petrol is derived from Australian mineral deposits with a distinct isotopic signature.

With an understanding of the natural and man-made variability of PHEs in the environment and techniques to distinguish between natural and man-made sources and investigate bioavailability and bioaccessibility, geochemists and soil scientists can aid the assessment of contaminated land. However, in Scotland at the present time, information on background levels of contaminants in soils is limited. Of the two main datasets available, the MLURI National Soil Inventory only provides information at 1 site per 10 km² and no data on As, Hg, or Se are included. The BGS G-BASE programme provides detailed (1 per 1.5 km²) information for As, Cd, Cr, Ni, Pb and Se but not for Hg and the data refer to stream sediments, not strictly soils. It is envisaged that the dataset in preparation for the Glasgow conurbation will provide more information.

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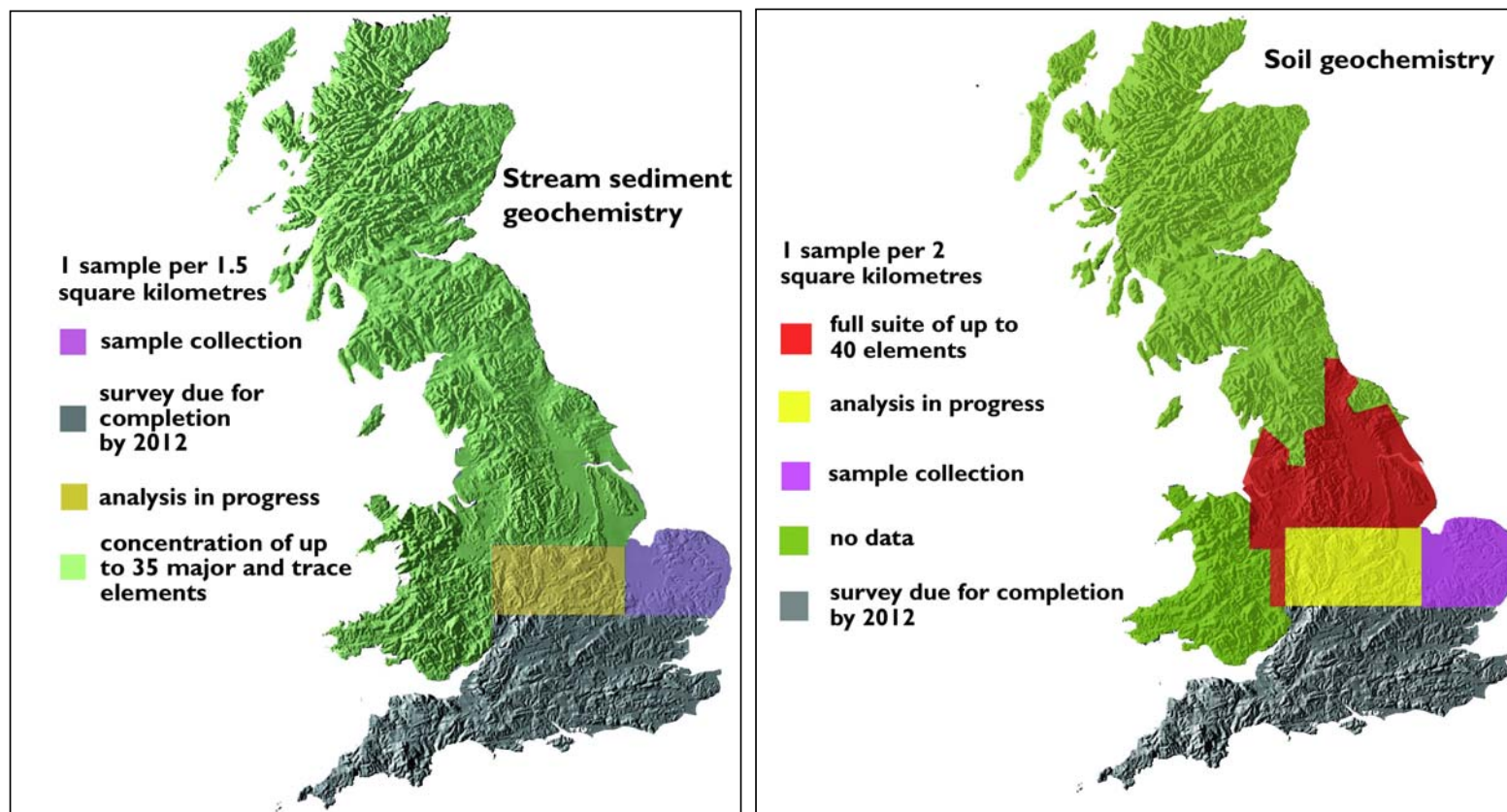


Figure 1. Availability of G-BASE stream sediment and soil geochemical data